

# Decoding the Amplitude-Modulated Part the DCF77 Longwave Time Signal by using the Goertzel Algorithm

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**Abstract**—The DCF77, a long wave time signal transmitter that is located near Frankfurt am Main in Germany, is the primary source of time information for radio-controlled clocks in Europe. Its signal consists of a phase and an amplitude-modulated part, both containing the time information. Devices that use the signal usually consist of an amplitude modulation long wave receiver, often realized by using a dedicated integrated circuit, and an application processor. In this paper, an alternative approach for the demodulation of the amplitude-modulated part of the signal, without the need for specialized analog circuitry and only a minimal amount of simple hardware components, is presented. This is done by utilizing direct-sampling software-defined radio techniques together with leveraging the efficiency of the Goertzel algorithm. As a result, the presented approach removes the need for most of the usually employed analog circuitry, leaving only a front-end amplifier, and therefore effectively proposes a new type of design where the receiver is implemented inside the application processor. The employed lightweight algorithms keep it realizable on a system with limited resources, which is shown in an example implementation on a Arm Cortex-M3 microcontroller.

**Index Terms**—DCF77, Goertzel, Digital Signal Processing, Time Signal, Software Defined Radio

## I. INTRODUCTION

Radio controlled clocks are very popular because they don't require periodical re-adjustment in comparison to common mechanical or quartz-powered clocks. Instead, the information about the current time is obtained from a RF-signal that is transmitted by an official authority that ensures its availability and correctness. The probably most important time signal in Europe is transmitted by the station DCF77 from Mainflingen, a city in Germany that is close to Frankfurt am Main. The station is operated by a private company that is commissioned by the Physikalisch-Technische Bundesanstalt (PTB) which also supplies the current time information, generated by two caesium clocks and two caesium fountains. Its operating frequency lies in the long wave area at 77.5 kHz and the time signal uses simple modulation techniques (amplitude and phase-modulation) and transmits with 100 kW Effective Isotropic Radiated Power (EIRP) to enable the reception of the signal in relatively close distances (up to 2000 km) with simple technical equipment [2].

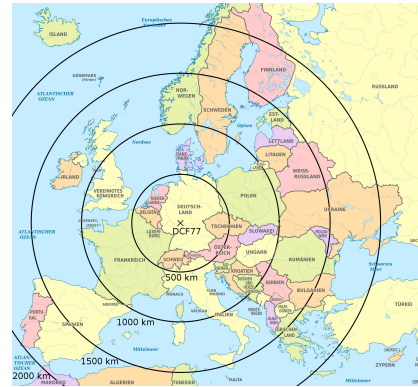


Fig. 1. Coverage of the DCF77 signal. Adapted from [1]

End-user devices usually make use of the amplitude-modulated part of the signal by using an amplitude modulation receiver, often a by employing specialized integrated circuit, together with a rather big ferrite-rod antenna to obtain the time signal. This time signal then needs further hardware, often in form of a microcontroller used as the application processor, to decode and retrieve the actual time information. With the increasing availability of computation power and Digital Signal Processing (DSP) capabilities inside cheap mixed-signal microcontrollers, which are already used to process the time information, the idea to replace the analog receiver portion with a Software Defined Radio (SDR) is more or less obvious. Moving the receiver into the application processor would allow for a simpler hardware design by shrinking down the complexity and the parts count of the external analog circuitry. In fact, only a tuned antenna with a basic pre-amplifier is needed.

In this paper, a straightforward principle for designing a lightweight receiver for the DCF77, based on SDR-techniques, is presented. After taking a look at the structure of the DCF77 signal, the theoretical operation principle of the receiver is explained and shown in a MATLAB simulation. To further underline the simplicity and the possibility to implement the principle on a system with limited resources, a demonstration

on a Arm Cortex-M3 microcontroller is shown.

## II. THE DCF77 SIGNAL

The DCF77 station operates in the long wave area at a frequency of 77.5 kHz. Its operation started with transmitting a frequency standard in 1959. In 1973, the transmission of the current time information was added to the signal by using amplitude modulation. To allow a reception under more challenging conditions and with a higher resolution and accuracy, the same time information is also added to the signal since 1983 by using phase-modulation [3]. The two different parts of the signal that result out of the parallel amplitude and the phase-modulation can be used for different use-cases that are separated by the requirements regarding the resolution, accuracy, and the reliability of the obtained time information. Whereas the amplitude-modulated part is mainly used for general-purpose time application with low resolution requirements, the phase-modulated part is usually used for specialized applications that require a higher resolution, accuracy, and reliability. Although being considered as low in comparison to what is achievable by analyzing the phase-modulated part, the usually observed accuracy uncertainty when using the amplitude-modulated part it is still well below 1 s, being 100 ms [2]. When using the phase-modulated part, a standard deviation of  $\pm 2 \mu\text{s}$  to  $\pm 22 \mu\text{s}$  from the atomic clock to the receiving device can be observed [4].

As the amplitude-modulated part allows simplistic receiver designs through its straightforward modulation scheme, it is used in the principle presented in this paper and therefore a focus is put on explaining this part of the DCF77 signal. The time information, represented as a series of binary symbols, is modulated onto the carrier with a frequency of 77.5 kHz by using Amplitude-Shift Keying (ASK). Every symbol has the duration of exactly 1 s, with a part that is either 100 ms or 200 ms long where it has a value to zero. This the duration of this "gap" is used to encode respectively a 0 or a 1 and effectively switches the strength of the carrier between 15 % and 100 % [5].

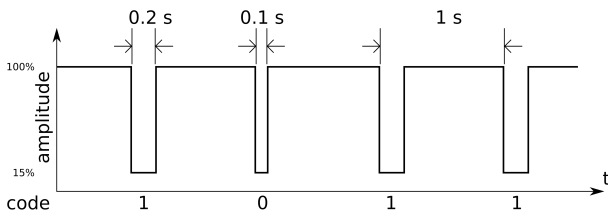


Fig. 2. Symbol encoding of the DCF77 signal. From [1]

To allow the detection of a new minute, the gap is left out between the last (59) second of the ongoing and the first (0) second of the next minute. By using this scheme, a dataframe consisting out 59 Bit, starting at second one, can be transmitted every minute. Bit 0 to 19 are used to send encrypted weather data, to notify the PTB in case of errors in the transmitter, to announce an upcoming switch to or from Daylight Saving Time (DST), to show if DST is currently

enabled or not, and to announce an upcoming leap second [5]. As the decryption of the weather data requires a specialized third-party integrated circuit and the notification bit is only important for the PTB, these parts of the frame are discarded by most applications. The leftover Bits 20 to 58 are used to represent the current time and date in Binary Coded Decimal (BCD) format, including parity bits for recognizing errors.

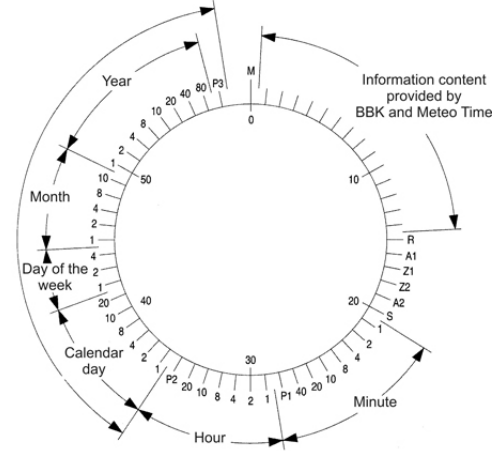
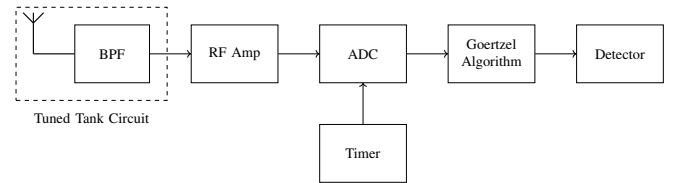


Fig. 3. Data frame encoding of the DCF77 signal. From [5]

This means that a receiver needs to run at least for 39 s after powerup to receive one whole block containing the current time information. In reality, this period is usually longer because the receiver needs to adapt to the current receiving conditions. These conditions underly a lot of influences, including temporary fading, electromagnetic noise from the close environment or varying signal strengths during different times of the day.

## III. PRINCIPLE OF THE RECEIVER

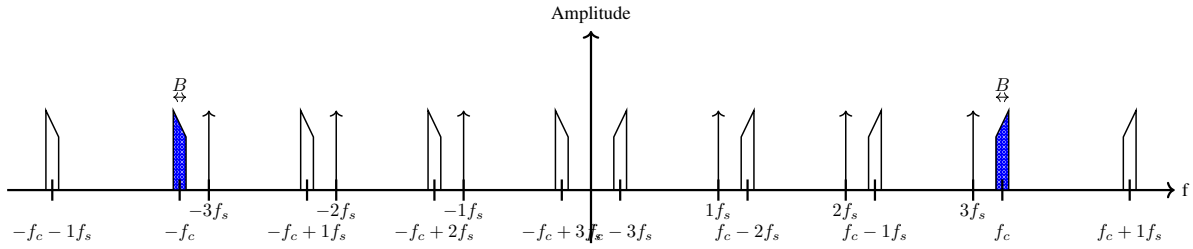
To understand the principle of the receiver, it is compared to the common structure that is used in radio controlled clocks.



Test

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TABLE I  
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Table Head	Table Column Head		
	Table column subhead	Subhead	Subhead
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<sup>a</sup>Sample of a Table footnote.

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#### ACKNOWLEDGMENT

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For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [?].

## REFERENCES

- [1] -, “DCF77,” 2024, Wikipedia entry. [Online]. Available: <https://de.wikipedia.org/wiki/DCF77>
- [2] D. Priester and P. Hetzel and A. Bauch, “Zeit- und Normalfrequenzverbreitung mit DCF77,” PTB Mitteilungen, 2004, [Online]. Available: [https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung\\_4/4.4\\_zeit\\_und\\_frequenz/4.42/dcf77.pdf](https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_4/4.4_zeit_und_frequenz/4.42/dcf77.pdf)
- [3] D. Priester and P. Hetzel and A. Bauch, “Zeit- und Normalfrequenzverbreitung mit DCF77: 1959-2009 und darüber hinaus,” PTB Mitteilungen, 2009, [Online]. Available: [https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung\\_4/4.4\\_zeit\\_und\\_frequenz/pdf/2009\\_Bauch\\_PTBM\\_\\_DCF77.pdf](https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_4/4.4_zeit_und_frequenz/pdf/2009_Bauch_PTBM__DCF77.pdf)
- [4] P. Hetzel, “Time dissemination via the LF transmitter DCF77 using a pseudo-random phase-shift keying of the carrier,” PTB Braunschweig, 1988, [Online]. Available: [https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung\\_4/4.4\\_zeit\\_und\\_frequenz/pdf/5\\_1988\\_Hetzel\\_-\\_Proc\\_EFTF\\_88.pdf](https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_4/4.4_zeit_und_frequenz/pdf/5_1988_Hetzel_-_Proc_EFTF_88.pdf)
- [5] -, “DCF77 webpage,” 2024, Official page of the PTB [Online]. Available: <https://www.ptb.de/cms/en/ptb/fachabteilungen/abt4/fb-44/ag-442/dissemination-of-legal-time/dcf77.html>